5.—"ZEBRA ROCK" FROM THE EAST KIMBERLEY.*

By

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2.—INTRODUCTION.

Attention seems to have been first directed to this rock in 1924 when two specimens were collected by Mr. T. Blatchford, and described by Dr. Larcombe. The collection of specimens which are here described was obtained by Professor Clarke in 1926, and the appearance of typical specimens is illustrated in Figs. 17, 18 and 19.

3.—FIELD OCCURRENCE.

The specimens were obtained from about 3 miles S.W. of Argyle Downs Station, and the field relations of this rock were described by Professor Clarke in field notes as follows:—

"*Zebra Rock.*"—This occurs on a low ridge striking between 50° and 55° and traceable for about half a mile. At the northern end are large outcrops of red sandstone like that noted close to Mt. Misere, but here standing on edge, while half-a-mile or so to the east are large flags of Salterella limestone. One therefore has the choice of correlating the Zebra Hills vertical sandstone with the steeply dipping, but not vertical sandstone, of the hills near Mt. Misere or with the vertical quartzites and phyllites which are thought to be of late Pre-Cambrian age. On the whole it seems more likely that they are the equivalents of the dipping sandstone and therefore are at the base of the Salterella series and are of middle or lower Cambrian age. Followed to the south-west along the strike the sandstone is seen to be interbedded with red shaly mudstones which apparently thicken in this direction and the sandstone becomes more quartzitic and also shows a banded contorted structure. In the shale begin to appear white circular spots. As one moves farther south-west these spots become more numerous and coalesce. Most stages can be found between the spotted rock and the well known striped red and white rock. The only explanation that suggests itself to me is that some process of leaching began at certain centres possibly where crystals of pyrite occurred in the rock and these leached areas gradually extended. After leaching had proceeded to a certain stage it was superseded by infiltration with silica which led to the formation of the Zebra rock. At the south

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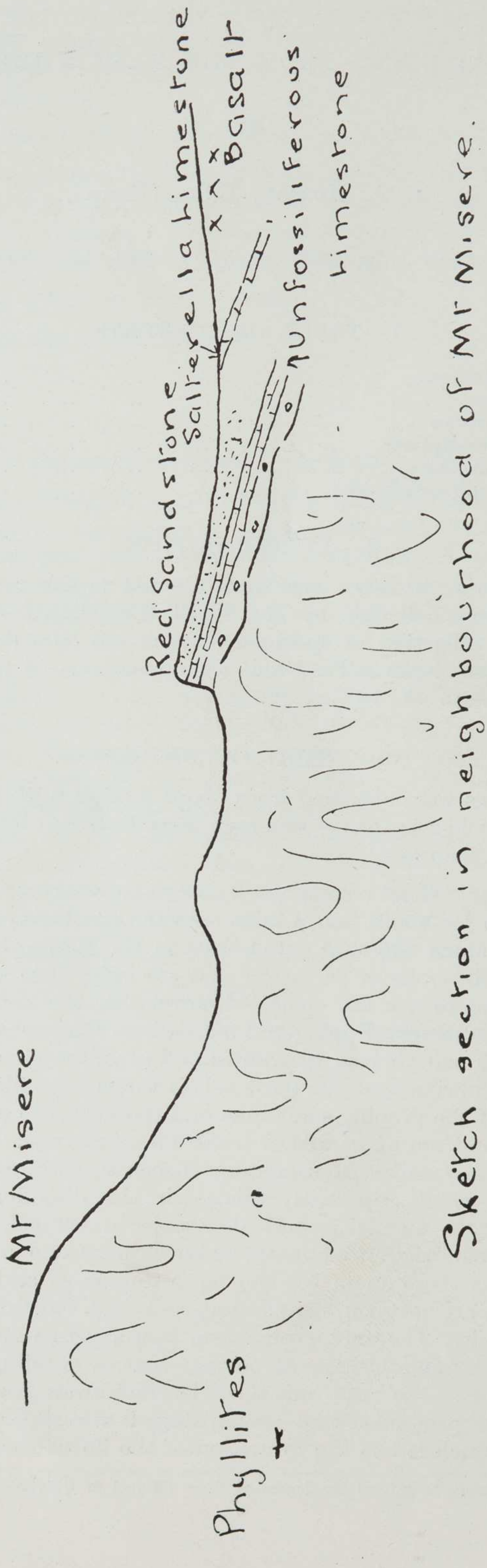
Mt Misere
Red Sandstone
Salterella Limestone
Basalt
Unfossiliferous Limestone
Phyllites
Sketch section in neighbourhood of Mt Misere.

Fig. 16.

end some of the *sandstone* also shows the zebra banding to a minor extent. Specimens of the unstriped mudstone and of a peculiar but rare greenish hard sandstone were also collected with the idea that they may represent the original rock."

4.—PREVIOUS DESCRIPTIONS.

Larcombe, C. O. G. (1924).—(i) Two rocks are described, one from the Ord River. The other from the Oakover River (in the N.W. Division) is evidently similar to the Zebra rock. He notes that "the ferruginous patches pass by insensible gradations into the surrounding clay rock." He concludes that the rock has been deposited in deep water far from land, that the coloured patches have been caused by "oxide of iron deposited from iron bearing solutions that have segregated along these specific areas" and that the two specimens are similar.

Larcombe, C. O. G. (1926).—(ii) Describes a banded rock from "4 miles east" (iii) of the Argyle Station. He notes that the rock consists of red and white bands, not sharply marked off from each other and that it is similar to rocks described above. For the origin of the rock he suggests deposition of alternate layers of ferruginous and non-ferruginous material, or, where the bands are not continuous, segregation of the iron oxides.

Blatchford, T. (1927).—(iv) With locality map and photograph of rock. He describes the field occurrence and appearance of the rock and agrees that it probably is due to leaching out of the iron oxide, but notes that there seems to be no reason why the coloured bands should be so regular. Specimens were obtained about three miles to the S.W. of the Argyle Homestead.

Through Dr. Simpson I have obtained the following analysis :—

Red and grey banded shales, Argyle Downs, East Kimberley (4 miles east of Homestead) (iii).

	Red Bands.	Grey Bands.
SiO_2	59·80	63·41
Al_2O_3	23·45	25·11
Fe_2O_3	5·73	1·12
FeO	·18	·02
MnO	*Nil*	*Nil*
MgO	·17	·11
CaO	·20	*Nil*
Na_2O	·08	·12
K_2O	·82	·82
H_2O —	·37	·35
H_2O + ...	8·45	8·82
TiO_2	·57	·44
CO_2	*Nil*	*Nil*
P_2O_5	·17	*Nil*
FeS_2	*Nil*	*Nil*
C	*Nil*	*Nil*
$B_2O_3ZrO_2$	trace	trace
	99·99	100·32
Sp. Gr.	2·61	2·61

Analyst: H. P. Rowledge, 1926.

(i) Larcombe, C. O. G., Ann. Pro. Rep. Geol. Survey, W.A., 1924, p. 19.
(ii) " " " " " 1926, p. 23.
(iii) Rocks described by Dr. Larcombe and analysed by Dr. Simpson are described as coming from four miles *east* of the Argyle Station. It is thought probable, however, that this should be four miles west of Argyle and that they were obtained from the same place as the rocks described in this report.
(iv) Blatchford, T., Ann. Pro. Rep. Geol. Survey, W.A., 1927, p. 14.

5.—DETAILED PETROLOGY.

Specimens examined in detail.—These were selected from numbers 7040–7053 of the general collection of the Geology Department of the University of W.A. Sections were cut from most of them and from some the heavy minerals were isolated. As the percentage of heavy minerals present was found to be very small it was necessary to take large samples for separation. From 400 to 1,000 gram samples were used and even then only small quantities of concentrate were obtained. The rock samples were crushed to pass through a 30-mesh sieve and the isolation of the heavy minerals was effected by panning and the use of bromoform, etc., in the usual way.

7040.

According to the field notes this is a typical specimen. The rock has in some places red cylinders or rods with a diameter of ½in. to 1in., and in other places red bands distributed through the white matrix. If the specimen is broken at right angles to the longer direction of the cylinders, then these are seen to be regularly arranged and to have a more or less oval cross-section. This is shown in Fig. 17. The red spots are arranged

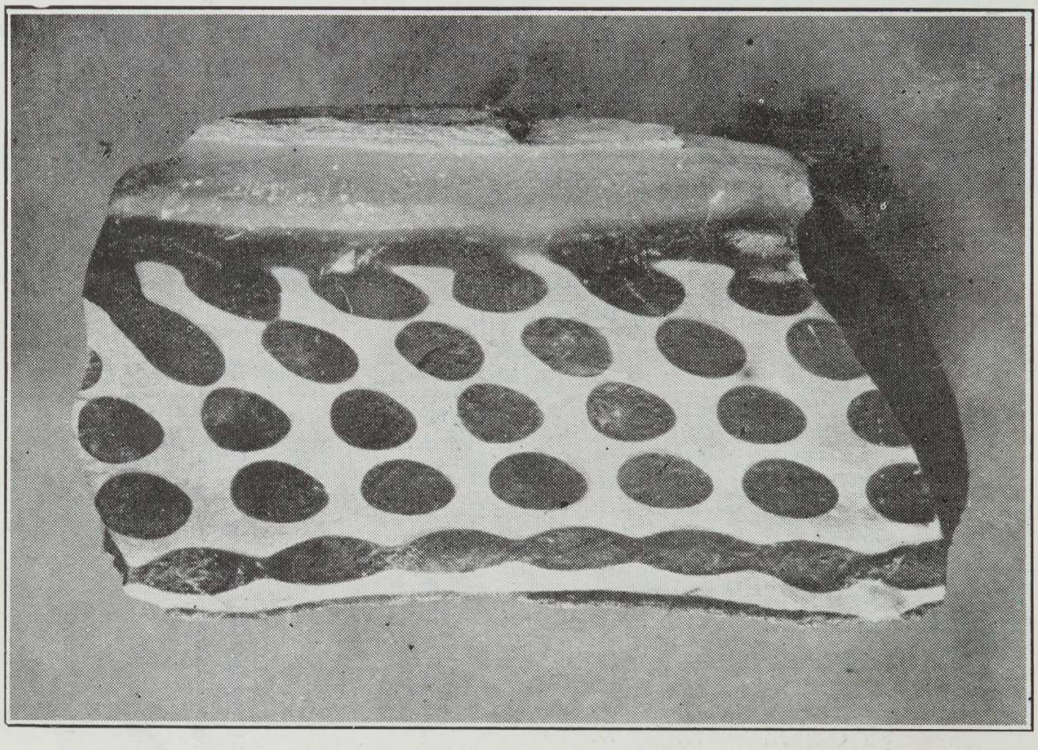

Photo.: H. Smith. Spec. 7040 x 9/20.

Fig. 17.—Zebra rock from the Kimberley Division, showing the oval shape of the rods when broken at right angles to their longer direction and their regular arrangement. Also the transition between the bands and the rods.

parallel to the base and also to the right hand edge of the specimens. The two top rows show a gradual transition from the red bands to separate red "spots." From the left to the right the separation of the "spots" becomes more complete and indicates a transition from one to the other. At the bottom of the specimen there also seems to be a transition from a band to a row of "spots" (*or* more accurately rods). When the rock was broken

parallel to the longer direction of the rods it was found that the rods, although continuous for some distance ended at a certain point and other rods commenced not far away (Fig. 18), the important point being that the rods

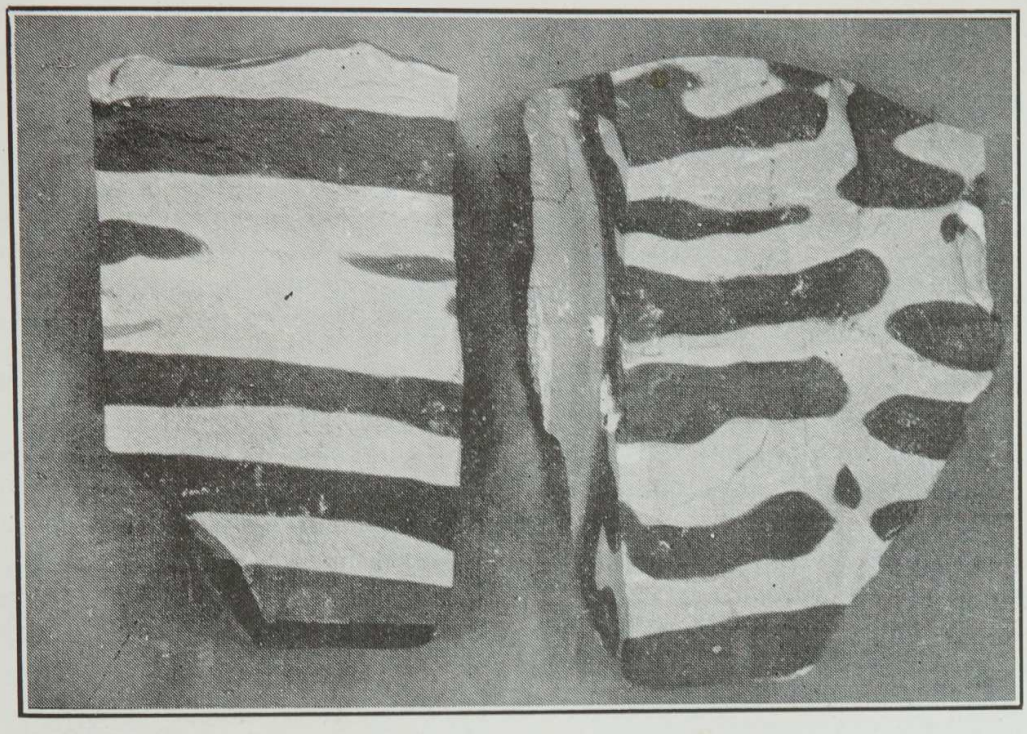

Photo.: *H. Smith.* Spec. 7040 x 1/3.

Fig. 18.—Zebra rock broken parallel to longer direction of the rods.

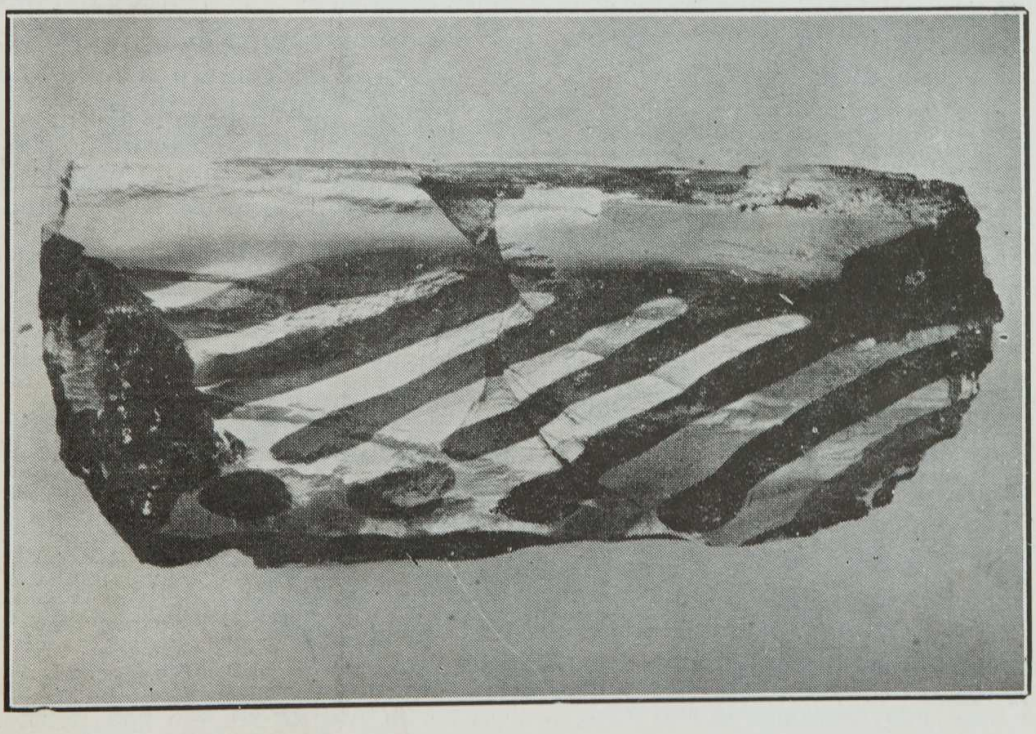

Photo.: *H. Smith.* Spec. 7040 x 1/3.

Fig. 19.—Zebra rock showing parallel bands and the transition from these to rods.

are not indefinitely continuous. Some specimens show a different arrangement (Fig. 19). In this there are parallel bands showing a gradation into spots. From the right to the left of the specimen the spots become more and more separate from the bands. Notice that the arrangement of the bands is similar to that of the "spots" previously shown in Fig. 17. This would suggest that the bands may have formed first and that the spots have gradually separated from the bands.

Under the microscope the rock is seen to consist of minute grains of quartz with an aluminous cement. The red portions are opaque unless the section is very thin. In thin places the red portions of the rock appear similar to the white portions with the addition of ferric oxide and the boundary between the two is sharp. With crossed nicols the similarity of the two portions is more evident.

For the determination of the heavy minerals of the red and the white portions the rock was broken up into small fragments and the red and the white portions of the rock were separated. The heavy minerals of each were determined with the object of finding differences or resemblances. If the two portions had been deposited at different times then each might have a different suite of heavy minerals. The percentage of heavy minerals in each is :—

7040—white portion .... ·015 per cent.

red portion .... ·002 ,,

The heavy minerals of the white portion of 7040 are Magnetite, Ilmenite, Leucoxene, Hornblende and Andalusite (?). The first three minerals are most abundant and leucoxene grains may be white or brown. Hornblende occurs as green grains with ragged edges with pleochroism from light green to dark green. Only a few grains of andalusite (?) occur. The heavy minerals of the red portion of 7040 are larger in size than those of the white portion and also less abundant. Magnetite and ilmenite grains are scarcer and leucoxene grains are often of the brown variety. Hornblende grains are larger and more abundant than in the white portion. Tourmaline fragments occur showing very strong pleochroism and also single fragments of Titanite, Spinel (?), Corundum (?), and Zircon (?) were observed. Owing to the small quantity of the concentrate obtained, the identity of these mineral fragments must remain doubtful. Thus there are differences between the heavy minerals of the two portions.

7042.

"*Red and white banded argillite, less perfectly banded with a predominance of red.*" The rock is mainly red-coloured, but contains white bands irregularly distributed. On one face the specimen shows an arrangement of red and white bands, similar to but less regular than that illustrated in Fig. 19. The boundaries of the lighter coloured bands are in some portions of the rock very indefinite and the colour is a light brown. These may be ntermediate between the white and the red portions of the rock.

Under the microscope the rock is seen to be similar to the red portions of 7040.

The percentage of heavy minerals was found to be ·012 and it should be noted that this is nearer to the percentage in the white portion (·015%
)

of 7040 than to the percentage in the red portion (·002 %). Magnetite, Ilmenite and Leucoxene make up the main portion of the concentrate. Hornblende, similar to that found before, and also one doubtful fragment of titanite, are present. Thus the heavy minerals of this concentrate (7042—red) resemble those of white portions of 7040.

7044.

"*Red argillite with suspicion of white bands of the broader type.*" The surface of this specimen shows small circular white areas represented by small holes on the weathered surface. These are found both in the white and in the red portions.

Specimen number 7044 was found to contain ·009 % heavy minerals. Magnetite, Ilmenite and Leucoxene were abundant. Andalusite (?) was also present.

7046.

"*Spotted red and white argillite—red being predominant—possibly by the coalescence of these white spots in such a rock as this the fine banded red and white argillite would be formed.*" The specimen shows white spots of irregular shape and size irregularly distributed in a red matrix. The average size of the white spots would be about ¼in. in diameter. Specimen 7048 consists of alternate dark and light reddish bands with white spots similar to those in 7046 in the lighter-coloured bands. The banding in 7048 is quite regular, but the specimen is small.

In section the rock (7046) was found to consist of quartz grains, there being no difference in shape, size, etc., between the grains in the red and those in the white portions. The boundary between the red and white portions is sharp.

7049.

"*Banded argillite, ripple-marked. Banding is clear, but not so sharp as in* 7040 *or* 7041. *Appears to be parallel to the bedding planes, and there are numerous pinholes due to leaching.*"

In section the rock appears to be similar to previous rocks. It is slightly coarser-grained and contains areas from which quartz grains are absent, and in which the cementing material is concentrated. A few wisps of mica are present.

The ripple marks referred to in catalogue description form a series of more or less parallel ridges and troughs with a wave length of less than ½in.

7050.

"*Red argillite associated with* 7040. *It is current bedded or slightly squeezed and shows some banding parallel to stratification. Also shows pinholes.*"

The specimens catalogued under 7050 showed considerable variation in grain size, from typical fine-grained specimens to coarse sandstone. The specimens examined were :—

7050A—Specimen showing current bedding (?)

7050B—Coarse-grained specimen.

7050C—Specimen showing inclusion (?) of coarse-grained rock in fine-grained rock.

7050A.

Under the microscope the rock was found to consist of quartz grains of an irregular shape but all about the same size. Grains are larger than those in previous rocks. Banding seen in the hand specimen is due to grains of iron oxide arranged in parallel bands. With the exception of the presence of the ferric oxide these bands are quite similar to the rest of the rock. Wisps of mica and a few small grains of tourmaline are also present.

7050B.

In the hand specimen it is seen to be a sandstone with a ferruginous cement and showing bedding planes. In general appearance the rock is light coloured or red, due to iron oxide, but there are also dark-brown patches distributed irregularly throughout the rock.

Under the microscope the rock was found to be a typical sandstone consisting of quartz grains of an irregular size and shape with a cement of silica and iron oxides. Some of the grains show secondary silica grown in optical continuity around previously rounded quartz grains (Fig. 20). The iron oxide in the cement is concentrated into layers. Small fragments of white mica are present.

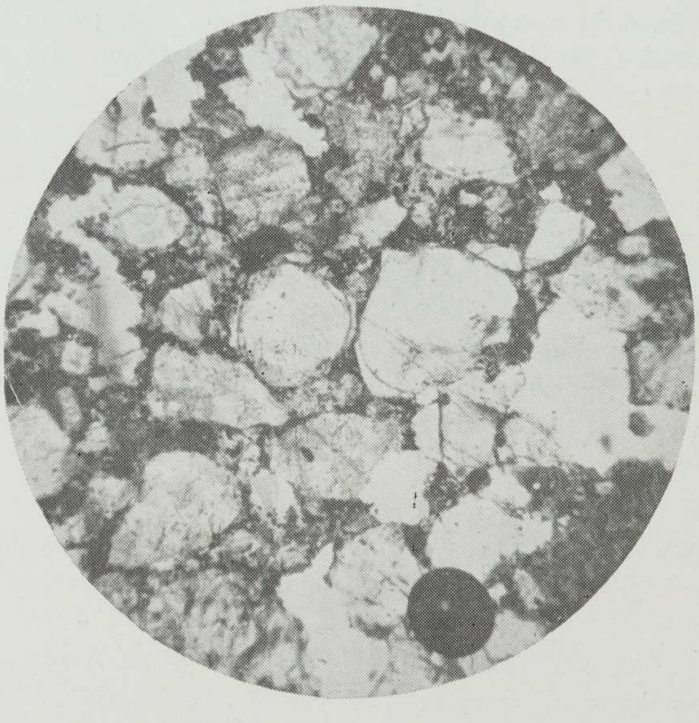

Photo.: *H. Smith.* Spec. 7050 x 12.5.

Fig. 20.

Showing the general appearance of the sandstone and the growth of secondary silica around rounded quartz grains.

This rock was found to contain ·011 % heavy minerals, consisting of Tourmaline, Zircon, Magnetite, Ilmenite and Leucoxene. Zircon is the most abundant mineral in this concentrate, and the grains vary considerably in form from perfect crystals to irregular fragments. Tourmaline grains are fairly abundant but vary in form and in pleochroism. Thus there is a difference between the heavy mineral suite of this sandstone and that of the rocks previously described, but it must be remembered that there is also considerable difference in grain size.

Photo.: H. Smith. Spec. 7050 x 12.5.

Fig. 21.

The same under crossed nicols showing optical continuity of the secondary silica.

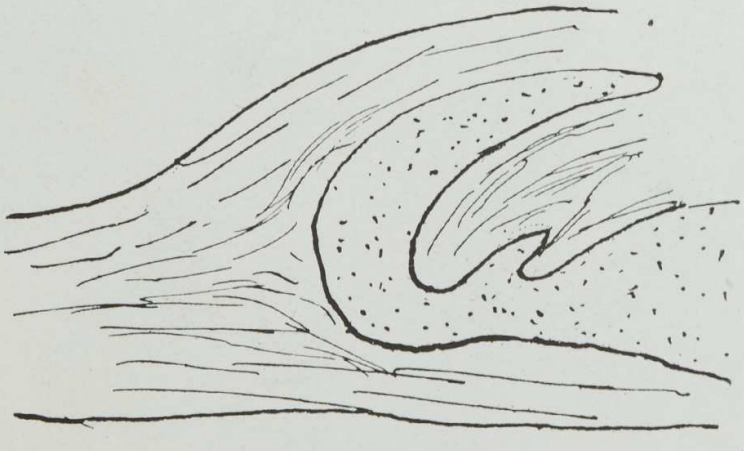

Fig. 22.—Showing coarse-grained sandstone surrounded by fine-grained material.

7050C.

The peculiar feature of this specimen is the apparent inclusion of a pebble of coarse-grained sandstone in finer grained material. The appearance of the specimen is shown in photographs 23 and 24.

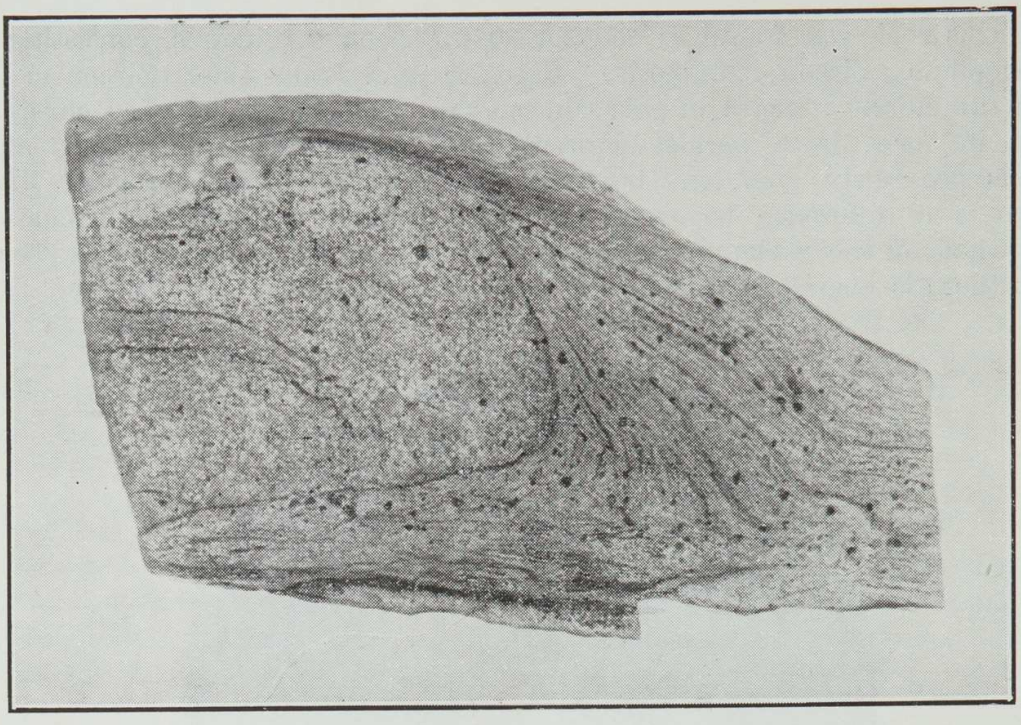

Photo.: H. Smith. 7050 x 10/9.

Fig. 23.—Showing the appearance of the specimen on the weathered surface.

The unweathered surface shows the bedding planes of the fine-grained material wrapped around the coarse-grained fragment. A polished surface —parallel to the previous one, but on the opposite side of the specimen— showed a different arrangement of coarse and fine-grained material.

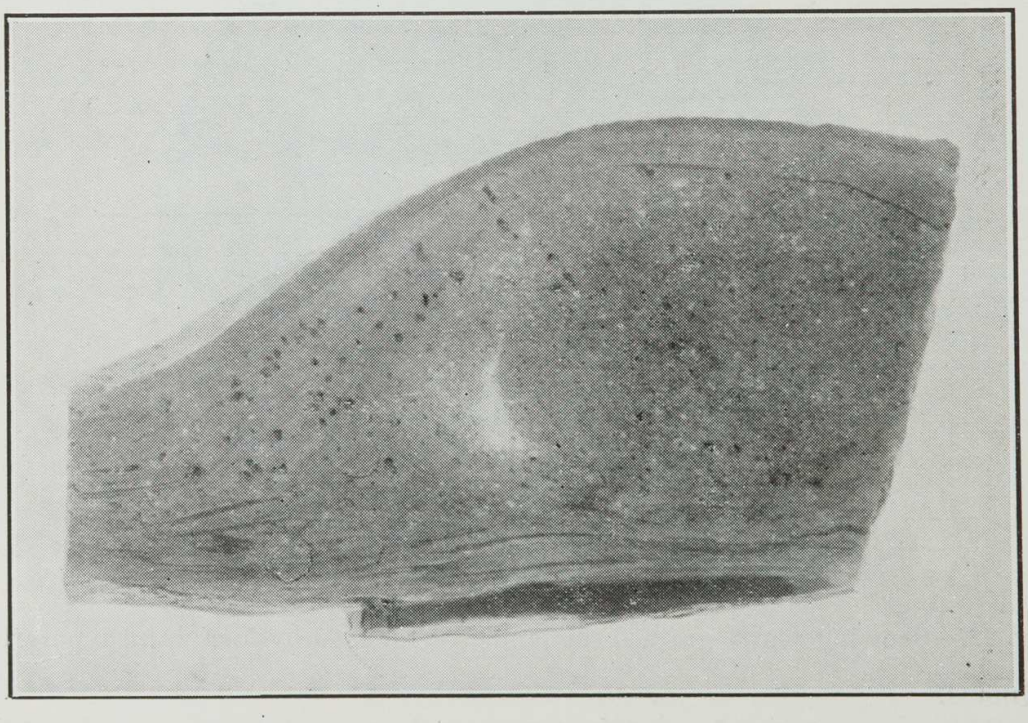

Photo.: H. Smith. 7050 x 10/9.

Fig. 24.—Showing a polished surface of the specimen.

Whether or not the coarse-grained material is part of a relatively small inclusion in the finer-grained material cannot be decided from the specimen. From the arrangement shown in the photographs it would be conceivable that the fine-grained material had been deposited around the coarse-grained fragment, but the arrangement of coarse and fine material in the above sketch would not be likely to result from this process. Professor Clarke has suggested that this specimen may represent a sandy bed which has slumped into an unconsolidated bed of finer-grained material. The boundary between the coarse and fine parts is quite sharp.

Under the microscope (Fig. 25) the rock was found to be made up of quartz grains with a cement of silica and iron-oxides. The coarser material resembles number 7050B, while the finer material is similar to the previously described fine-grained rocks, but it must be remembered that there is also considerable difference in grain size.

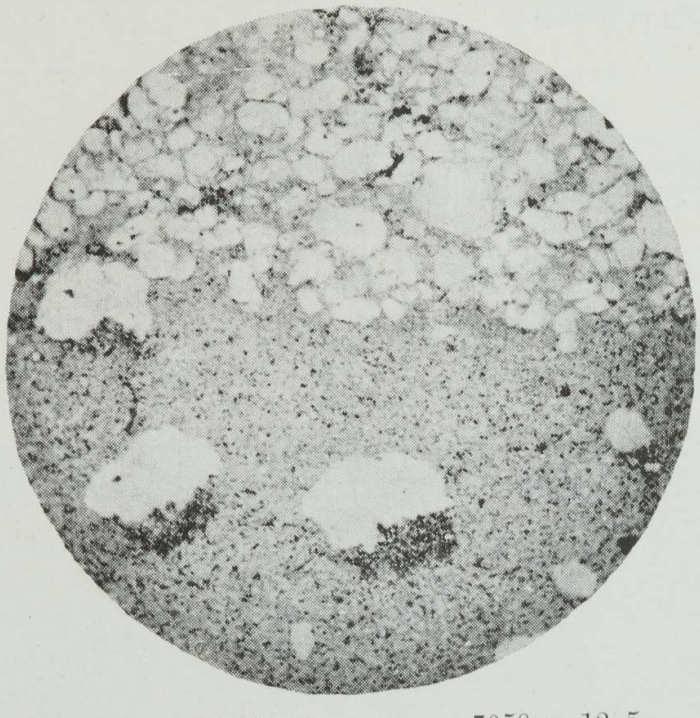

Photo.: H. Smith. 7050 x 12.5.

Fig. 25.—Showing coarse and fine-grained portions of 7050C and the sharp boundary between the two. (The large white patches in the lower portion of the picture are holes in the section.)

7051.

"*Red argillite shows no banding or spotting. It is perhaps the original rock from which the Zebra rock developed by leaching, etc.*"

This was examined for heavy minerals with the idea of comparing these with the heavy minerals of the typical zebra rock. The percentage of heavy minerals was found to be ·001 per cent. (*c.f.* red portion of typical rock) and consisted of magnetite, ilmenite, leucoxene with hornblende, together with single fragments of zircon, pyrite (?) and andalusite (?). The small quantity of the concentrate obtained renders accurate determination of the less abundant fragments impossible. Apart from the quantity these minerals are very similar to those obtained from other rocks.

7053.

"*Greywacke* (?) *associated with the red and white argillite belt.*"

In the hand specimen the rock is a chocolate colour showing fragments of felspar with crystal faces. Also a green mineral can be seen. Rock is evidently very weathered.

Under the microscope the rock is seen to be altered, but is certainly an igneous rock. Two generations of felspar occur. Phenocrysts are not abundant and are very altered. The extinction angle varied between 0° and 28°, and in one place traces of lamellar twinning were seen. Felspars of the groundmass are hypidiomorphic and show lamellar twinning. There is present a colourless mineral with high polarisation colours and having a higher relief than the associated felspar. It is often twinned and is bi-axial. In one place two cleavages at 90° were seen and the same crystal was bi-axial and positive. Extinction angle is large. The mineral is colourless augite. Green chloritic material and iron-oxides are also present. Rock is therefore a basalt.

Specimens not examined in detail.

Other specimens which are included in the field collection made by Professor Clarke, but which have not been examined in detail in the laboratory, are :—

7041.

"*More finely banded than* 7040."

Also banding is less regular. This is illustrated in Fig. 26.

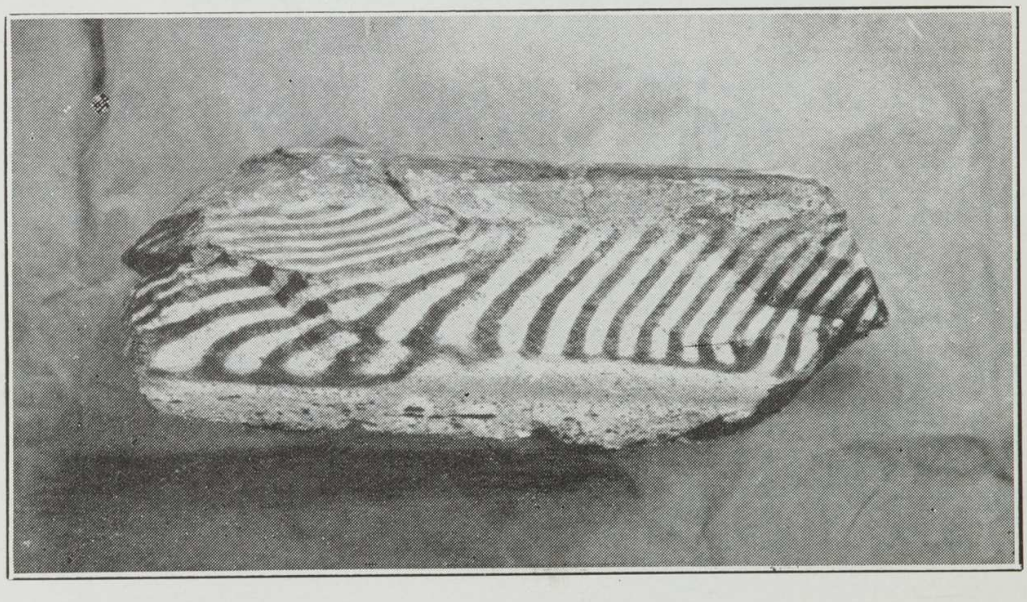

Photo.: H. Smith. Spec. 7041 x 9/20.

Fig. 26.

Finely banded zebra rock.

7043.

"*Red and white banded argillite—finer banded type. Banding less perfect than* 7041. *Red colour predominant.*"

7045.

"*Red argillite with shadows of white bands due to more or less regularly aligned whitish spots*—(?) *due to leaching.*"

This rock is coarser-grained than typical zebra rock and approaches to the sandstone of 7050. In this rock there is a predominance of the dark brown colour noted in 7050.

7047.

"*White and red argillite. An exceptional type, in which the white predominates.*" (Small specimen.)

7048.

"*Red and white banded argillite, but the light bands are still reddish except where white spots occur.*"

Note that the white spots are restricted to the lighter coloured bands. (Small specimen.)

7052.

"*Red argillite but shows portions of a lighter colour.*"

There is a gradual transition from red rock to lighter coloured rock.

6.—SUMMARY AND CONCLUSIONS.

The typical Zebra rock from the East Kimberley consists of very small quartz grains with an aluminous cement. In parts of the rock iron oxide is present, causing the strange appearance of the rock. Sections show that the boundary between the red and the white portions is sharp, but that the general appearance of each (except, of course, that due to iron oxide) is similar.

——	Heavy Minerals.	Magnetite.	Ilmenite.	Leucoxene.	Tourmaline.	Titanite.	Spinel.	Corundum.	Zircon.	Andalusite.	Hornblende.
7040 (white) ...	·015%	×	×	×	...	...	...	...	...	×	×
7040 (red) ...	·002%	×—	×—	×	×	1	?	?	?	...	×+
7042 (red) ...	·012%	×	×	×	...	...	...	...	...	...	×
7044	·009%	×	×	×	?	...	...	...	...	×	...
7051	·001%	×+	×	×	...	...	...	...	?	?	×
7050B	·011%	×—	×—	×	×+	...	...	...	×+	...	...

The above table gives the heavy minerals of the rocks examined and indicates that there are differences between the red and white portions of the typical rock, both in total quantity of the minerals present and also in the quantities of tourmaline and hornblende. In view of the small amount of the concentrates obtained and the similarity in quantity of heavy minerals of the red portion of 7042 to the white portion of 7040, I feel that little stress

can be laid on these differences. Further, the chemical analysis of each is very similar (i), the most significant difference being the increase (4·61%) of iron oxide in the red portions. This demonstrates the small quantities of iron oxide required to colour a rock strongly. I think that the two portions of the rock must be regarded as very similar. Associated rocks vary in grain size from fine-grained rocks to coarse sandstones. Banding somewhat similar to that of the typical rock is found in other specimens, but bands may be a different width or may be less strongly defined or both. Many of the rocks are mainly red with only a few white portions, and in some white circular spots with a definite boundary are found (ii).

Origin of the Zebra Rock.

It seems impossible to imagine that the typical zebra rock, and also many of the associated rocks, have originated in the way suggested by Dr. Larcombe for the banded rock examined by him, *i.e.*, by alternate deposition of ferruginous and of non-ferruginous materials. Judging from the higher heavy mineral content of the white portion of 7040, it does not appear that that part was originally red and has been leached as suggested by Professor Clarke. Moreover, only one doubtful pyrite grain has been obtained. Nothing has been observed which suggests a cause for the very regular arrangement seen in the typical specimens.

(i) Chemical analysis is that given in the earlier part of the report. It should be noted that the rocks actually examined were not analysed.

(ii) Owing to Mr. Hobson's absence from Perth, it has been impossible to submit to him the proofs of this paper. The symbols used in the table on the preceding page appear from the context and from Mr. Hobson's laboratory notes to have the following significance :—

× present, × + abundant, × — rare, 1 single grain observed, ? doubtful.

[Editor, Journ. Roy. Soc., W.A.]